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NRL'S MARINE AND ENVIRONMENTAL HYDRODYNAMICS LABORATORY.(U)
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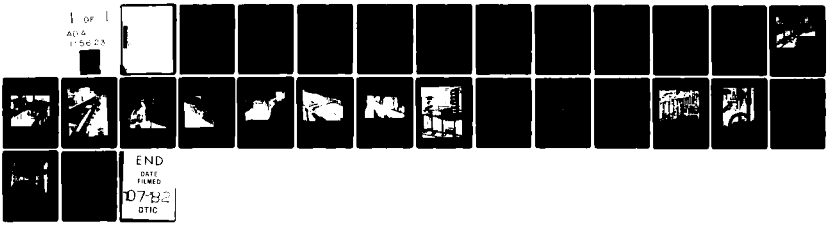

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the experimental facilities, instrumentation, and data acquisition and analysis systems that are available at NRL's Marine and Environmental Hydrodynamics Laboratory. The experimental facilities consist of two 30.5m (100 ft) wave/wind channels and an 18.3m (60 ft) stratified towing channel. A Digital Equipment MINC-11 laboratory computer and a Hewlett-Packard System 35 laboratory computer are available for experimental control, data acquisition, and data analysis. A wide range of supporting instrumentation also is available. Some brief examples are given of the research programs that are presently underway at the MEH Laboratory. (Continued)		

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20. ABSTRACT (Continued)

These programs include micro   ve radar oceanographic studies of the interactions and transport processes between long anu   t ocean waves conducted by the Environmental Sciences Division (Code 4300) and studies of the interaction between ocean waves and structures conducted by the Marine Technology Division (Code 5800). Experiments to model and characterize the wake hydrodynamics of Naval platforms in motion on and below the ocean surface also are conducted in the wave/wind and stratified towing channels.

CONTENTS

NRL'S MARINE AND ENVIRONMENTAL HYDRODYNAMICS LABORATORY

INTRODUCTION

During the past decade, marine and environmental fluid mechanics research has been underway at the Naval Research Laboratory. As an example, basic studies of flow-induced structural vibrations, wave effects on structures, and wake hydrodynamics have been undertaken as part of the applied mechanics program of the Marine Technology Division. Radar oceanography experiments to elucidate the energy transfer mechanisms between oceanic winds, wind-generated waves, and ambient ocean waves have been conducted at NRL for many years and since 1973 these wind-wave interaction studies have formed part of the physical oceanography program of the Environmental Sciences Divison.

In order to provide at a relatively modest cost an experimental facility in keeping with NRL's expanding basic research programs in fluid mechanics, construction was begun during 1975 on a multipurpose wave-wind channel laboratory. The project was a joint venture of the Environmental Sciences and the Marine Technology Divisions (Codes 4300 and 5800 of NRL) and the facility has been designed to accommodate experiments ranging from the study of wind and wave effects on marine structures to the dynamic interactions between the oceanic wind and waves. The original channel was equipped initially with a regular wave generator and a centrifugal fan-powered wind tunnel for the generation of wind waves. The present laboratory facility consists of two wave-wind channels and the stratified towing channel and is described here.

Typical examples the research programs currently being conducted at the facility also are described briefly in this report. A separate report (1) gives further details concerning the operational characteristics and capabilities of the stratified towing channel.

A GENERAL DESCRIPTION OF THE LABORATORY

The wave channel and towing channel facilities are housed in an enclosed laboratory constructed within a much larger NRL structure designated as Building A59. A floor area approximately 46m (150 ft) by 18.3m (60 ft) has been enclosed and includes a high bay area which is ventilated for summer use and heated in winter, and adjacent laboratory rooms which are both heated and air-conditioned for year-round environmental control. The high bay room comprises a total of 520m^2 (5540 ft^2) in floor area and the ceiling elevation of this area varies between 10m (33 ft) and 11.5m (38 ft) from the floor level. The environmentally controlled laboratory rooms are approximately 375m^2 (4000 ft^2) in area with ceiling heights of between 2.4m (8ft) and 3.05m (10 ft). The latter areas provide a controlled environment for small-scale laboratory experiments and equipment calibration, and for the location of sensitive computer systems, and for data acquisition systems in use at the adjacent wave and towing channels.

The facility presently houses two 30.5m (100 ft) multipurpose research channels with their associated wind and wave generator systems as well as a 18.3m (60 ft) stratified towing channel and salt water mixing system. These research channels are described in detail in the following sections.

Manuscript submitted January 21, 1982.

THE WAVE CHANNELS AND WIND TUNNELS

The "Deep Water" Wave Channel

The general layout of the "deep water" wave channel and some details of its construction can be noted in the photograph shown in Figure 1. This overall view of the laboratory was taken before the construction of the second wave channel. The channel has a length of 30.5m (100 ft), a width of 1.2m (4 ft) and a total depth of 1.8m (6 ft). The design water depth is 1.5m (5 ft) but the typical operating condition consists of a water depth of 1.1m (3.5 ft) or less and a wind channel of 0.76m (2.5 ft) or greater measured from the still water level. The beach end of the tank is equipped with two vertical baffles which serve to maintain constant water depths of 0.55 and 1.1m (1.5 and 3.5 ft).

The framework of the channel is constructed of welded steel I-beams and angle sections. The channel bottom is raised 30.5cm (12 in) above the floor to provide access to the underside of the tank for photographic, lighting, and instrumentation purposes. The horizontal frame members which run along the top of the channel contain fixtures for mounting the wind tunnel roof in several configurations. Two horizontal tracks for the movement and location of equipment carriages are welded to the vertical framing along the entire length of the tank.

The walls and floor of the beach and wavemaker ends of the channel are constructed of 6.4mm (0.25 in) thick stainless steel plates, 3.7m (12 ft) long, which are bolted in place and sealed with a polysulfide-based industrial caulking. The remaining channel walls are constructed of 25.4mm (1 in) transparent acrylic sheets 1.2m (4 ft) by 1.8m (6ft) in size and the channel floor is constructed of the same material 1.2m (4 ft) by 1.2m (4 ft) in size. Both floor and walls rest un a thin rubber pad. The joints between the bottom and side plates of the tank consist of a layer of polysulfide caulking. The walls and floor of the tank are nominally level and straight within $\pm$2.5mm (0.1 in).

The channel facility has been equipped with a carriage mounted, mechanically-driven vertical paddle for the generation of regular waves. A photograph of the system is shown in Figure 2. The stainless steel paddle is suspended on a precision ball bushing and shaft system and it is driven by a solid state control-motor-variable speed drive system which in turn is connected to a scotch-yoke mechanism mounted on the carriage and suspension. The clearance between the wavemaker and the tank walls is nominally 3.2mm (0.12 in). Spring-loaded teflon wipers provide low-friction contact between the walls and the paddle. The drive units for the generator mechanism are mounted above the tank and the paddle is attached to vertical struts for compatibility with the wind tunnel inlet to the channel. The wave generator carriage, which can be moved along the floor rails by means of a rack and gear system, allows the equilibrium position of the wave generator assembly to be located at various displacements from the end of the channel and provides access for the installation and removal of the wind tunnel sections. A porous-wall wave absorber to dissipate the fluid motion behind the paddle is mounted on the wall of the tank beneath the wind tunnel inlet.

The stroke and period of the wave generator can be continuously varied from ground level by means of a precision control system. The maximum stroke of the unit from equilibrium is 24cm (9.5 in) and it is designed to operate at frequencies up to 4 Hz. At a still water level of 1.1m (3.5 ft), deep water waves are generated at frequencies in the range of $0.8 < f < 4.0$ Hz and intermediate waves in the range $0.1 < f < 0.8$ Hz.

This wave-wind channel facility is equipped with a generator for the production of wind waves both singly and in combination with the regular waves. The fan, screen section and inlet are shown in the inset of Figure 1. The wind tunnel is powered by a 18.6 kw (25hp) constant-speed centrifugal fan with a variable inlet shutter, and the fan is mounted on the concrete floor by means of a spring-supported, concrete and steel inertial base. The fan outlet is connected to the wind channel through a flexible section, the screen section, and a 1.4:1 contraction duct, which in turn exits into the channel

proper. The turbulence intensity at the wind tunnel inlet to the tank is about three percent with four screens installed at the fan outlet.

The wind channel roof consists of plywood sections each 1.2m (4 ft) long. The roof sections can either be clamped to the upper horizontal frame members of the tank or suspended within the tank on removable frames.

A beach made of 12.7mm (0.5 in) acrylic sheets is supported by a framework of slotted steel angles which are coated with an epoxy-based marine paint. An array of equally-spaced 76mm (3 in) holes have been cut in part of the beach surface. This provides a porosity of 30 percent over the upper half of the beach length in order to assist in the attenuation of the incident wave energy. A blanket of rubberized fibrous material is installed over the acrylic sheets in order to provide optimum wave attenuation.

The beach is 7.3m (24 ft) in overall length and 1.2m (4 ft) in height at the downstream tank wall, and is comprised of two sections of different slopes. One section is 1.8m (6 ft) in length and has a slope of 15 degrees, while the remainder of the beach is 5.5m (18 ft) in length and has a slope of 7 degrees. The wave reflection coefficient (the ratio of reflected to incident wave amplitudes) is less than five percent for wavelengths between 0.6m (2 ft) and 2.7m (9 ft).

The "Shallow Water" Wave Channel

The "shallow water" wave channel is shown in Figure 3. The channel has a length of 30.5m (100 ft), a width of 2.4m (8 ft) and a total depth of 0.9m (3 ft). The water depth in the channel may be set at 15cm (6 in), 30cm (12 in), 37cm (15 in), or 45cm (18 in) by means of a series of baffles and drains at the beach end of the tank. The channel is designed to accommodate a smooth airflow over long, paddle-generated waves whose shape is electronically programmable.

The framework of the channel is very similar to that of the deep water channel. It consists of welded steel I-beams, the lowest of which is 0.3m (12 in) above the floor, with horizontal rails along the top for the movement of equipment carriages. Walls and bottom of the tank are 6.2mm (0.25 in) thick steel sheets with welded seams. A double coating of epoxy paint provides corrosion resistance. Five windows with dimensions 51cm (20 in) by 91.4cm (36 in) and constructed of 2.5 cm (1 in) thick plexiglass are spaced along the the tank walls to allow convenient viewing of the water surface. Four small windows with dimensions 30.5cm (12 in) by 46cm (18 in) and one large window with dimensions 1.16m (45.5 in) by 1.77m (69.5 in), all constructed of 2.5cm (1 in) thick plexiglass, are located in the bottom of the tank to allow illumination of optical experiments.

The fan and ductwork arrangement is shown in Figure 4. Wind is produced by a double-inlet, centrifugal fan with variable inlet vanes, a 1.13m (44.5 in) diameter wheel and an outlet opening with dimensions 1.26m (49.5 in) by 1.51m (59.5 in), the large dimension being horizontal. This fan is driven by a 18.6 kw (25 hp) motor and discharges into a sheet metal expansion chamber with a maximum cross section of 1.52m (60 in) by 2.43m (95.5 in) and a total length of 19 ft (5.86 m). Four removable screens just downstream from the widest point reduce the size of turbulent eddies while a shutter assembly in the ductwork makes possible rapid initial rise times for the airflow. The entire fan and ductwork assembly is isolated from the main body of the tank by flexible sections.

Figure 5 shows the system for generating long waves with programmable profiles. The paddle is located at the upwind end of the channel; plywood sheets separate it from the airflow above. The paddle is 53cm (21 in) high and 2.43m (8 ft) wide and is suspended from a carriage of dimensions 2.43m (8 ft) by 2.43m (8 ft) which rides on precision ball bushings on two stainless steel rails. Spring-loaded teflon wipers provide low-friction contact between paddle and channel walls. A 51cm (20 in) high

overflow baffle behind the paddle allows excess water to exit the tank on the backstroke of the paddle. An electonically-controlled servoactuator is mounted on the outside of one tank wall to provide hydraulic control of the carriage and paddle assembly through a lever arm. By varying the fulcrum of this lever, the maximum stroke of the paddle may be either 30.5cm (12 in) or 91.5cm (36 in).

The top of the tank is covered by standard-sized plywood sheets reinforced by angle iron which fits into the carriage tracks on top of the tank walls and also extends across the tank to allow roof sections to be clamped together. The water surface is separated from the airflow by plywood sheets which rest on steel supports welded to tank walls 53cm (21 in) above the bottom. By removing some of the lower plywood sections, the length of water in contact with the airflow, the fetch, may be varied. A beach at the downwind end of the channel acts as a wave absorber.

THE STRATIFIED TOWING CHANNEL

The general layout of the towing channel is shown in Figure 6. The channel is 18.3m (60 ft) long, 1.22m (4 ft) wide, and 0.91m (3 ft) deep. The construction of the channel is similar to that of the deep water wave channel described earlier. The framework is constructed of welded steel members with 1.83m (6 ft) long stainless steel sections at each end of the channel. The remaining sections of the channel are constructed of 25.4mm (1 in) thick transparent acrylic panels which rest on thin rubber pads. All of the joints between the steel and acrylic panels are sealed with polysulfide-based industrial caulking. The floor of the channel is raised approximately 30.5cm (1 ft) from the floor to accommodate photography and lighting from below.

The towing system. The channel is equipped with two independently-controlled tow carriages which move on rails installed along the top of the channel. The carriages are driven by a cable system that is, in turn, driven by a motor drive and clutch system which can be operated manually or by a laboratory computer/controller. Tow speeds up to 0.76m/s (2.5 ft/sec) are possible with both carriages. One of the tow carriages is shown in Figure 7.

The salt water mixing system. Stratification of the water is achieved by the introduction into the channel of a water-salt mixture. The desired salinity gradients are achieved by pumping and mixing fresh water and saturated brine through a complex series of holding tanks, valves and piping. The system consists of three 5320 l (1400 gal) tanks, one 1520 l (400 gal) tank, and two 950 l (250 gal) tanks, and a brine mixer. The system is shown in Figure 8.

The salt water is introduced slowly into the channel filled with fresh water through two 38.1mm (1.5 in) pipes which extend along the floor of the channel. These inlet pipes contain small diameter holes equally spaced along the length of the pipes. The salinity of the inlet water is continuously monitored and controlled automatically to achieve the desired stable stratification and mixture properties.

INSTRUMENTATION, DATA ACQUISITION, AND COMPUTER SYSTEMS

Wind-generated wave systems are investigated at NRL using coherent microwave scattering and photometric techniques as well as more conventional wave probes. Measurements of Doppler spectra using focused parabolic antennas at microwave-lengths of 0.4, 1.25, 3.2, 7 and 16 cm allow the detailed study of wind-generated waves 2 mm to 40 cm in wavelength by exploiting the Bragg scattering principle. Modulation of the wind wave system by longer paddle-generated will provide the means for studying wind wave equilibria. Real-time spectral analysis and correlation with dynamic ranges up to 70 dB are available as well as a digital acquisition capability with a sampling rate of 12,500 HZ at 12 bits. Diffraction analysis of water wave photographs is used to measure directional slope spectra for wavelengths between 1 mm and 10 cm. A Digital Equipment Corporation MINC-11 laboratory computer is available for processing radar oceanography data. This modular, multipurpose computing system is built around an LSI-11/23 CPU and has 256K bytes of random access memory. Dual RX02

floppy disc units, each with 500K byte capacity, and dual RL01 hard disc units, each with 5M byte capacity provide peripheral data storage capabilities. The system is programmable in BASIC and FORTRAN. Data acquistion, data analysis, and experimental control are all possible using this system.

A typical range of more or less conventional instrumentation is also available for flow and fluid-structure interaction measurements. Six channels of linearized hot-wire and hot-film anemometry sensors and the associated calibration and signal conditioning equipment are available for measurements both in air and in water. Three channels of bi-axial and single axis electro-optical displacement sensors and their associated signal conditioning equipment are available for monitoring the steady and unsteady motions of floating and submerged models. Several channels of voltage-gradient and capacitance wave height sensors together with the appropriate signal conditioning and recording systems have been calibrated for use in connection with on-going experiments at the facility.

The data acquisition and analysis capabilities of the MEH laboratory are enhanced by several additional devices and systems. These include a Hewlett-Packard 5420A digital signal analyzer and a Hewlett-Packard 9835 laboratory computer with a 64K byte storage capacity. A Hewlett-Packard 9885A flexible disk drive unit contains 500K bytes of additional storage. A Hewlett-Packard 2240A measurement and control processor provides the capability for experimental control, data analysis and communication between the various devices, which are connected together by an interface bus.

For processing flow visualization results a Colorado Video television frame storage system is linked to a television camera, monitor and video tape storage unit. The television frame storage system is, in turn, linked directly to the HP 9835 computer for enhancement and processing of the video data.

RESEARCH CONDUCTED AT THE MEH LABORATORY

Current radio oceanographic research in the Environmental Sciences Division is aimed at characterizing short gravity wave equilibria, the transfer of momentum and energy from the atmosphere to ocean waves, and the interactions and transport processes between long (100m or 328 ft) and short (6m or 20 ft and less) ocean surface waves (2, 3). A typical radar oceanography test set-up is shown in Figure 9. The perturbation of both air flow and short wind-generated surface waves by larger scale fluid motions is studied. Although microwave scattering is the principal experimental tool, the channels are also available for other wave measuring techniques. Calibration experiments for microwave, photometric and other types of wave probes used in allied measurements on the ocean also are carried out.

Figure 10 illustrates the utility of the microwave scattering techniques employed in the Environmental Sciences Division. The signal backscattered to a microwave system observing the wind-ruffled surface of a wind-wave channel is primarily caused by a single surface wave which satisfied the "Bragg resonance condition" given in the figure. This wave must be travelling either toward or away from the antenna in order for this resonance condition to be satisfied. Thus the backscattered signal exhibits a small frequency (Doppler) shift compared to the transmitted signal. The lower part of Figure 10 shows the power spectrum of the backscattered signal obtained when waves of wavelength λ_B (Bragg waves) travelling toward and away from the radar are simultaneously present on the water surface. The two sharp lines corresponding to the opposite travelling waves shifted approximately 4 Hz in opposite directions from the frequency of the transmitted signal, here designated as zero frequency. Theory and experiments show that this "Doppler shift" is exactly equal to the frequency of the Bragg wave. Thus using microwave radar, one can conveniently Fourier decompose a rough water surface and determine amplitude, frequency, and wavelength of selected Fourier components.

Using such information, phase speeds of individual wind-generated water waves can easily be measured. Figure 11 shows the result of one such series of measurements. The dashed line shows the phase speeds of different frequency waves which is expected on the basis of classical potential theory.

The measured phase speeds of waves travelling with the wind are always larger than those values primarily due to the drift current induced on the water surface by the wind. This current, which cannot be included in potential theory calculations, advects the wind waves and thereby increases their frequency in the laboratory frame of reference. A detailed explanation of this effect was recently published by NRL's Environmental Sciences Division (4).

One other example of the utility of microwave scattering in studies of wind-generated waves is illustrated in Figure 12. Here the intensity of a sharp spectral line such as shown in Figure 10 is plotted versus time after the wind was suddenly turned on over the water. Note that the growth of the Bragg wave responsible for the line was measured by the technique as the wave amplitude increased by a factur of 10^6. Such measurements have been used to examine theories of wave growth whose understanding is essential to predict features of wind-generated waves either in the laboratory or on the ocean.

The Marine Technology Division for several years has had on-going programs to study flow effects on structures and wake hydrodynamics. The objective of the first program is to investigate the effects of waves, wind and currents on structures in the marine environments. The objective of the second program is to characterize the behavior and hydrodynamic properties of laminar and turbulent wakes in homogenous and stratified fluids. Experiments in support of the former program are conducted in the deep water wave/wind channel, while experiments to support the latter program are conducted primarily in the stratified towing channel. One example of recent experiments conducted in the wave channel concerned the measurement of wave pressures on and reflections from a large bottom-seated, half cylindrical obstacle. Figure 13 shows a typical test set-up during experiments to study the effects of wave flow over submerged obstacles. A description of the experiments being conducted in the photograph is given in a recent overview of NRL research activities (5) and in a more detailed report (6). The half cylinder was placed in the wave channel as shown in Figure 14 and wave-induced hydrodynamic pressures on the cylinder were measured at nineteen equally-spaced pressure taps located around the circumference of the cylinder at its midsection. The incident and reflected wave height amplitudes were measured by an array of probes at the water surface. These experiments were used to validate several numerical and analytical methods for wave pressure prediction in the scattering/diffraction regime, and the results are discussed in a related NRL report (6). Some typical results are shown in Figure 15.

In a second research program conducted recently at the wave/wind channel, the wave force coefficients were measured in the drag/inertia (Morison) regime where the water particle motions are significantly larger than the characteristic structural dimension. The experimental set-up is shown in Figure 16. In this regime the oscillatory flow often separates from the body to form an unsteady wake. Standard empirical wave force calculations in this regime are still subject to uncertainties of 50 to 100 percent.

The sources of these uncertainties are being sought as one part of the NRL wave/structure interaction research program. The experimental measurements in Figure 17 illustrate the variations in the hydrodynamic force coefficients that are due to changes in the eccentricity of the water particle orbits. In the figure the rms wave force coefficients for a horizontal circular cylinder in waves vary by as much as 100 percent when the wave particle orbits pass from deep water conditions to the shallow water limit. These experiments are discussed in a recent paper and report (7).

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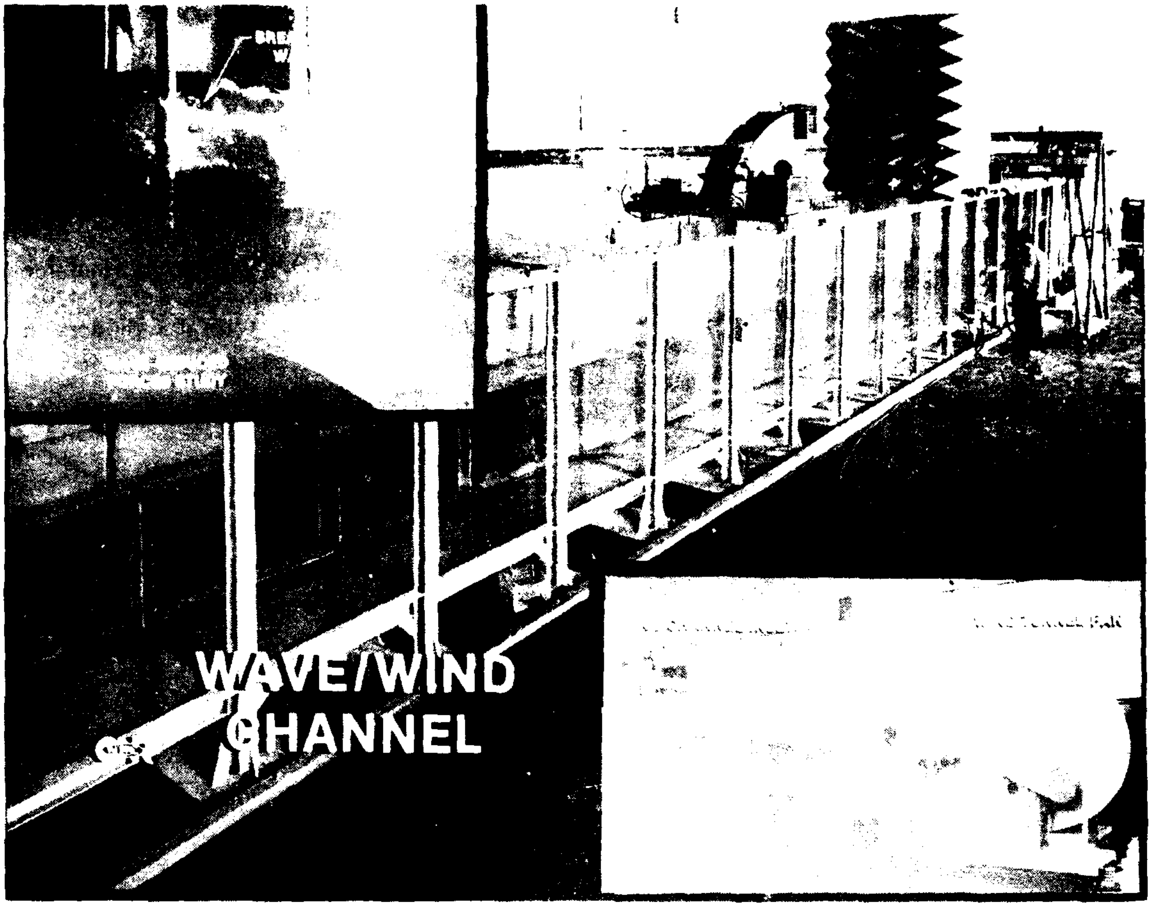

Fig. 1 — An overview of the multipurpose "deep water" wave/wind channel

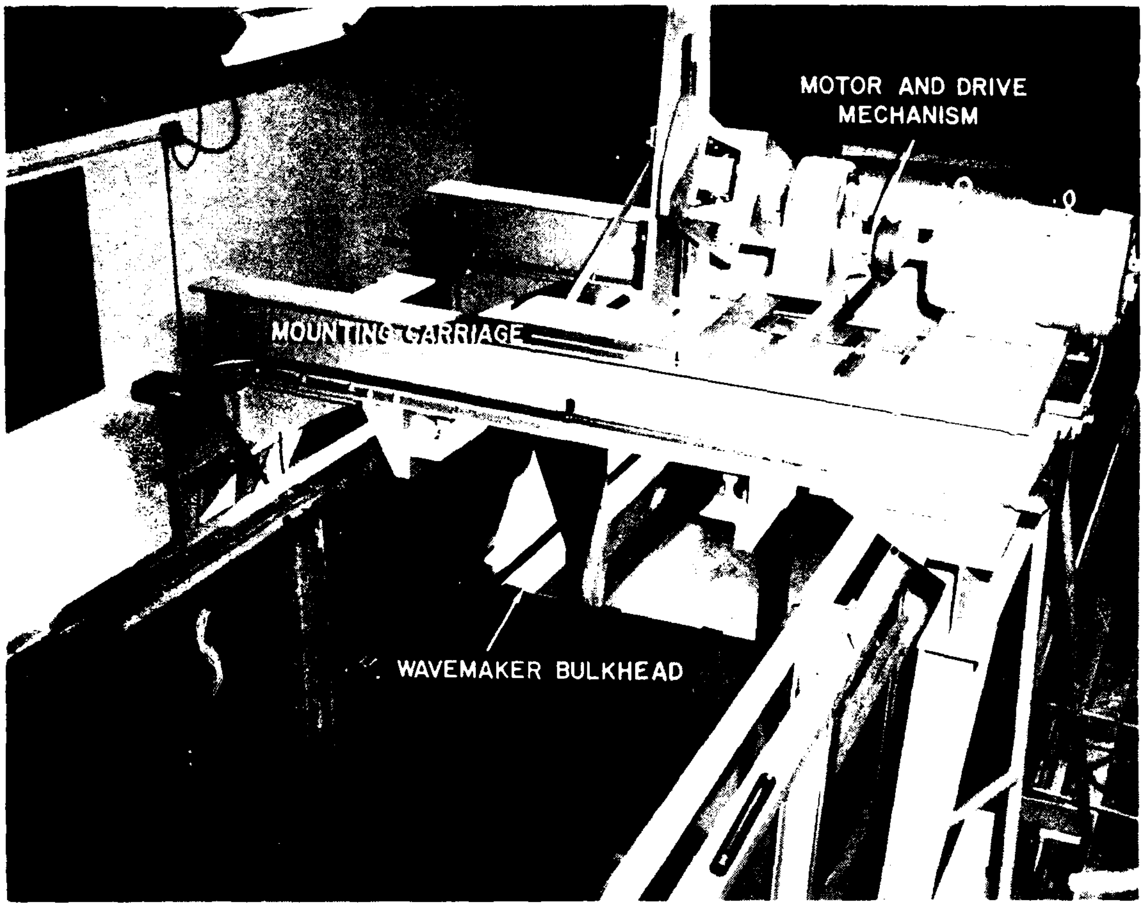

Fig. 2 — The mechanically driven vertical paddle and drive system for the generation of regular waves in the "deep water" wave/wind channel.


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Fig. 3 — An overview of NRL's multipurpose "shallow water" wind/wave channel

Fig. 4 — The fan and wind tunnel for the "shallow water" wave/wind channel.

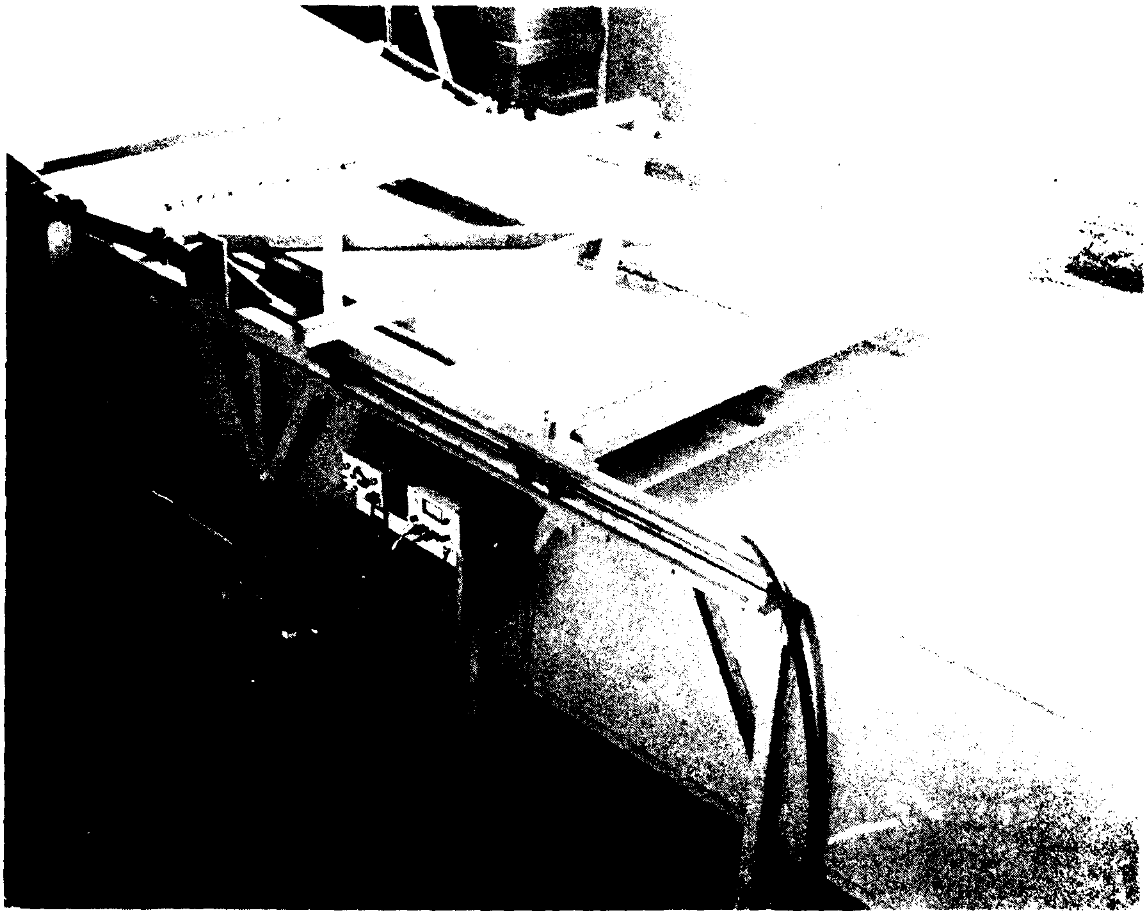

Fig. 5 — The hydraulically-actuated random wave generator system installed in the "shallow water" wave/wind channel.

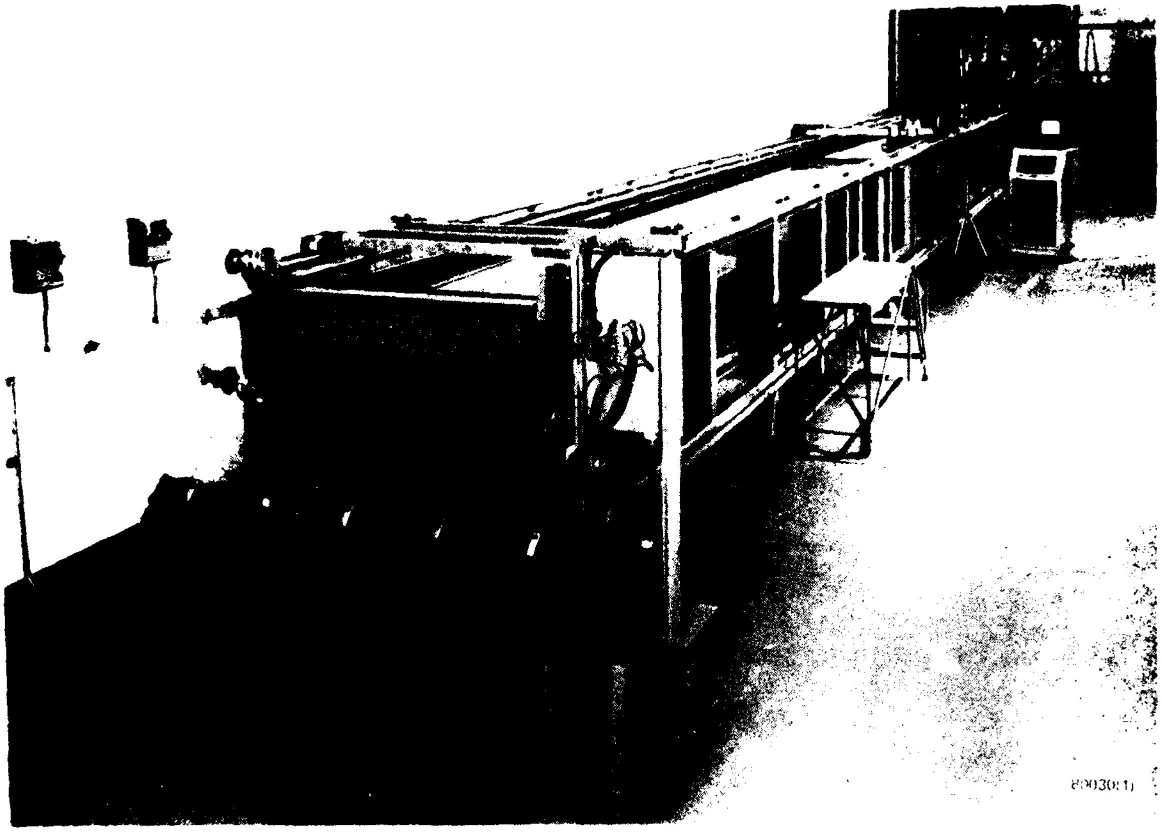

Fig. 6 — An overview of NRL's stratified tow channel. The salt water mixing system for generating stable density profiles in the channel is shown in the background. The clutch, motor drive and carriage control system are shown in the foreground.

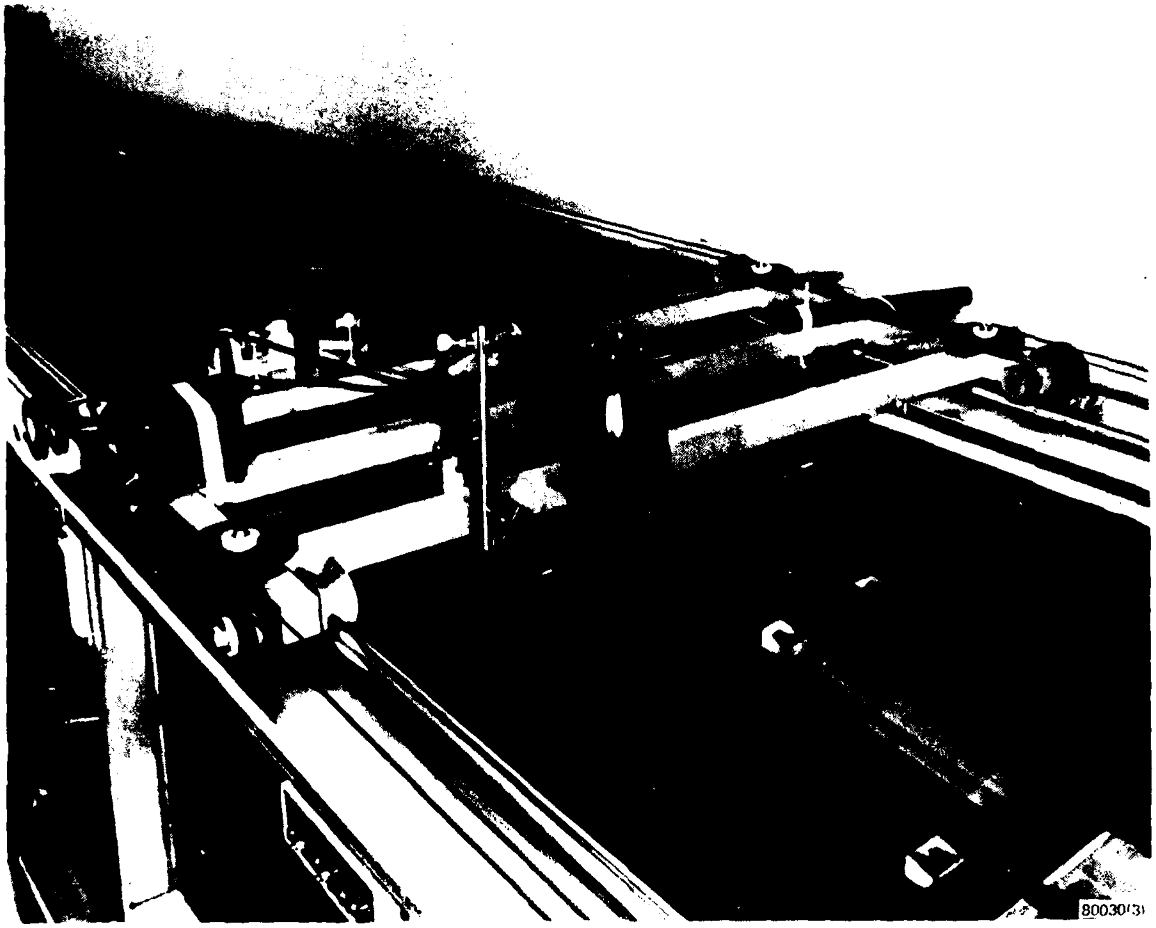

Fig. 7 — One of the two carriages installed on the tow channel is shown in the photograph. The carriages can be controlled independently to operate at speeds up to 2.5 ft/sec (76 [illegible]

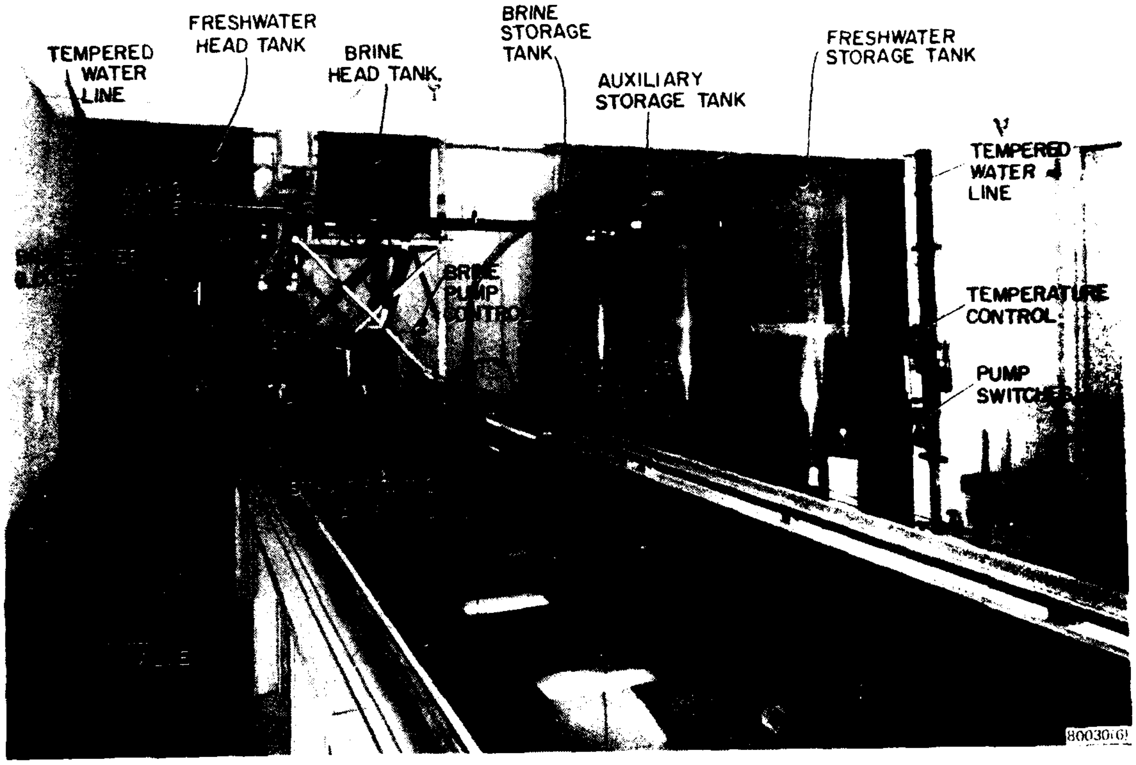

Fig. 8 — The salt water mixing system for generating stable density profiles in the tow channel. Several important features of the system are labeled on the photograph.

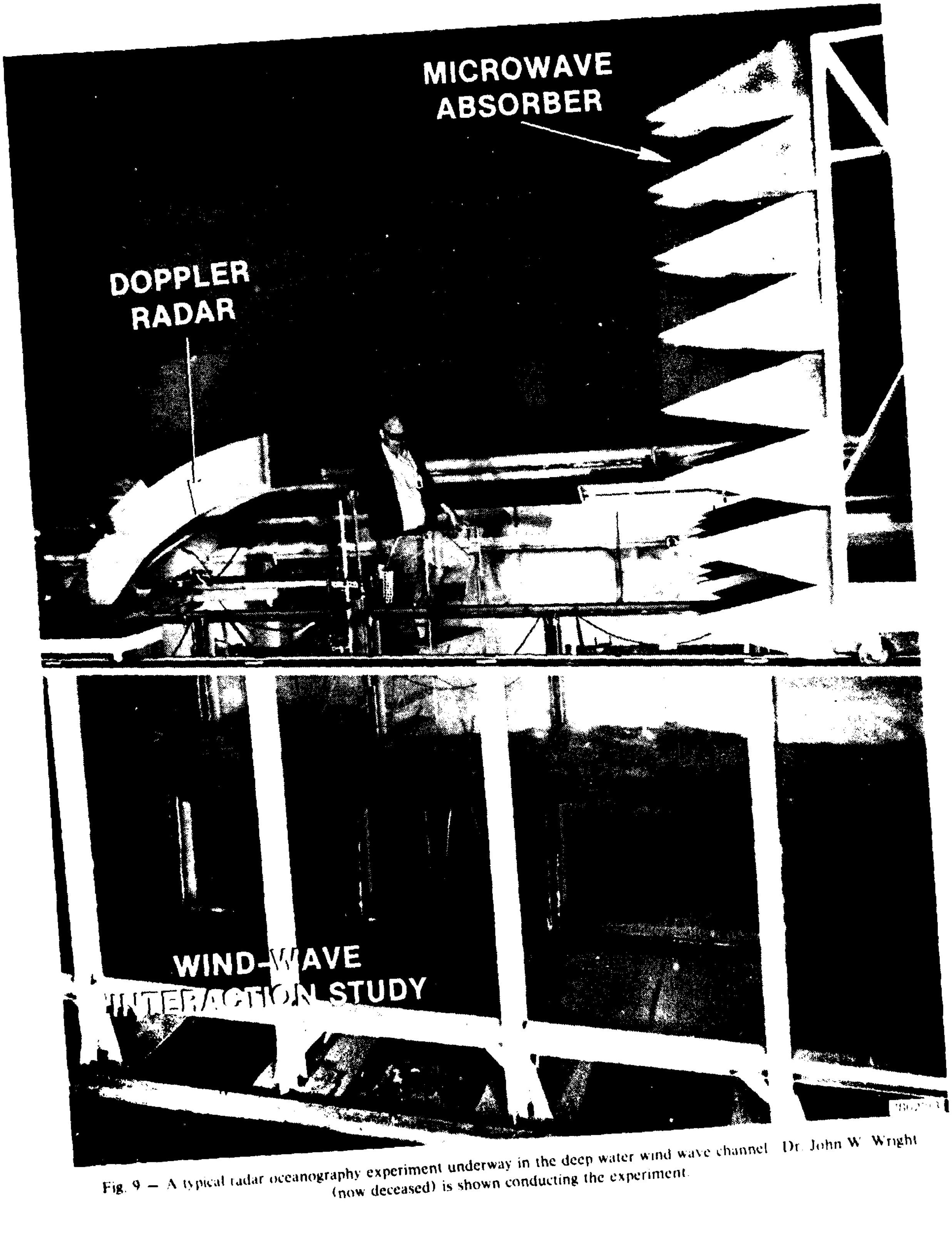

Fig. 9 — A typical radar oceanography experiment underway in the deep water wind wave channel. Dr. John W. Wright (now deceased) is shown conducting the experiment.

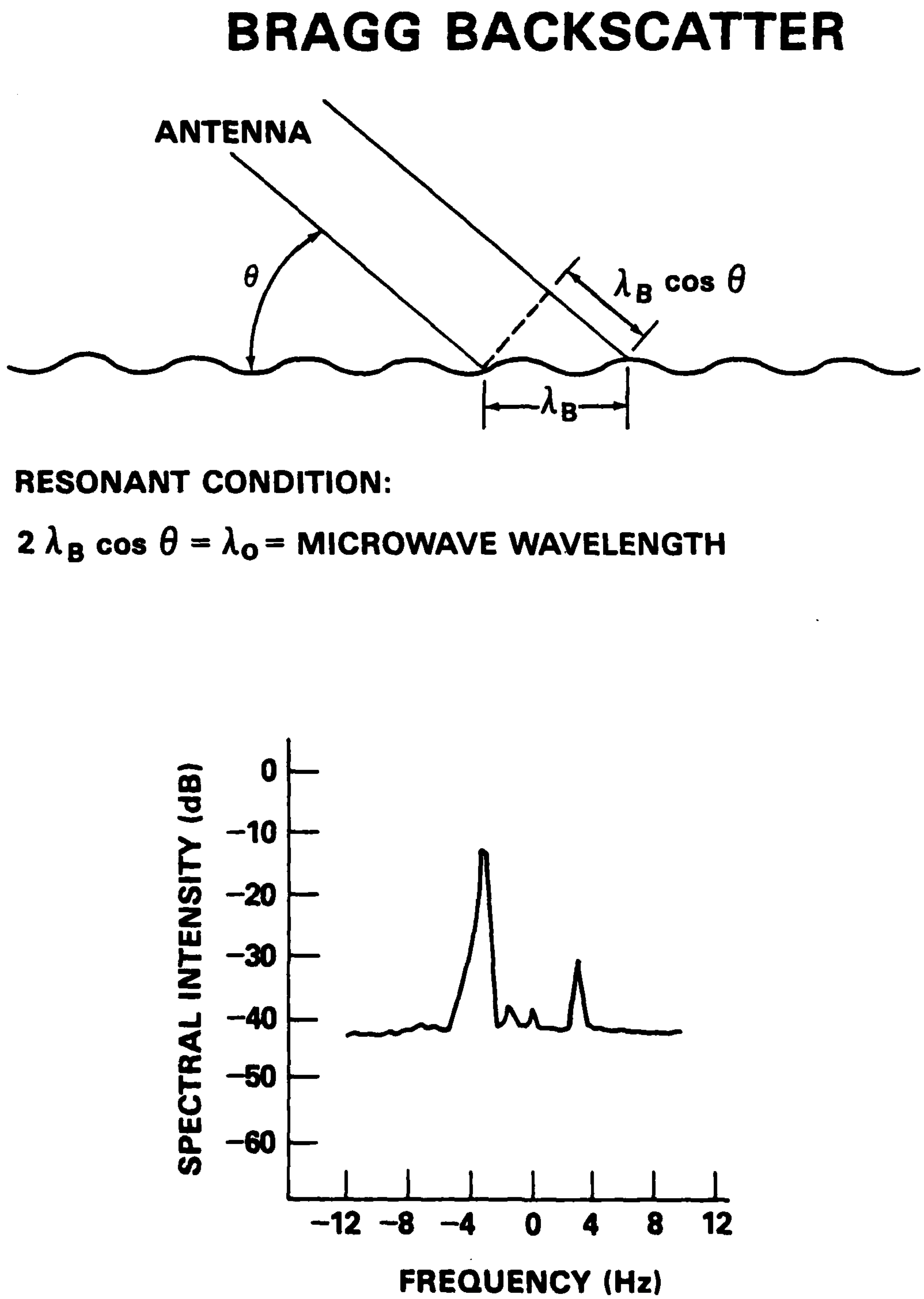

Fig. 10 — Illustration of microwave scattering from water waves. The upper part of the figure illustrates the Bragg resonance condition. The lower part shows a power spectrum of a microwave signal scattered from a wind-ruffled water surface.

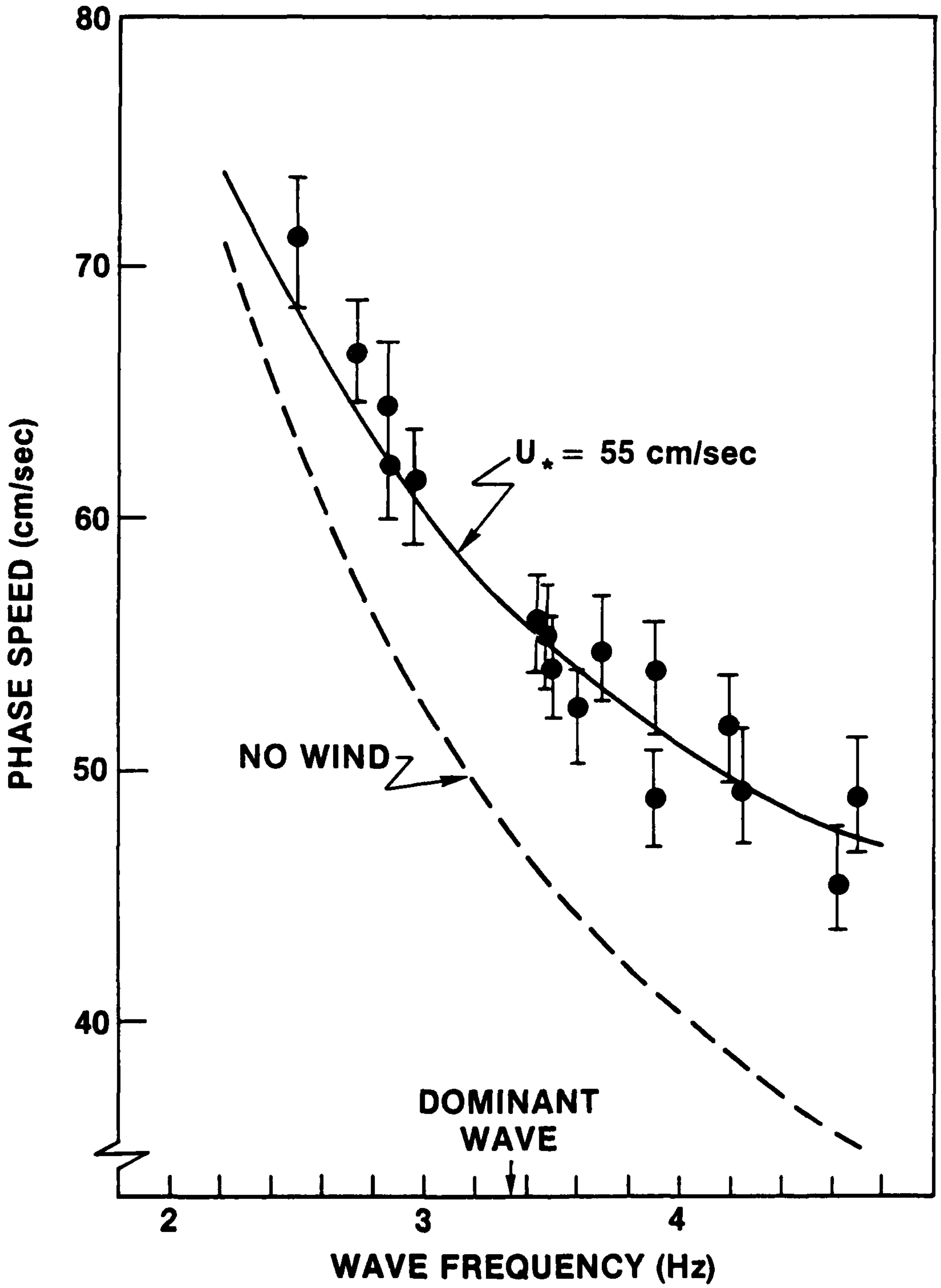

Fig. 11 — Microwave measurements of phase speeds of wind- generated water waves. Dashed line indicated values expected from potential theory. Solid line represents the theory of Plant and Wright (4).

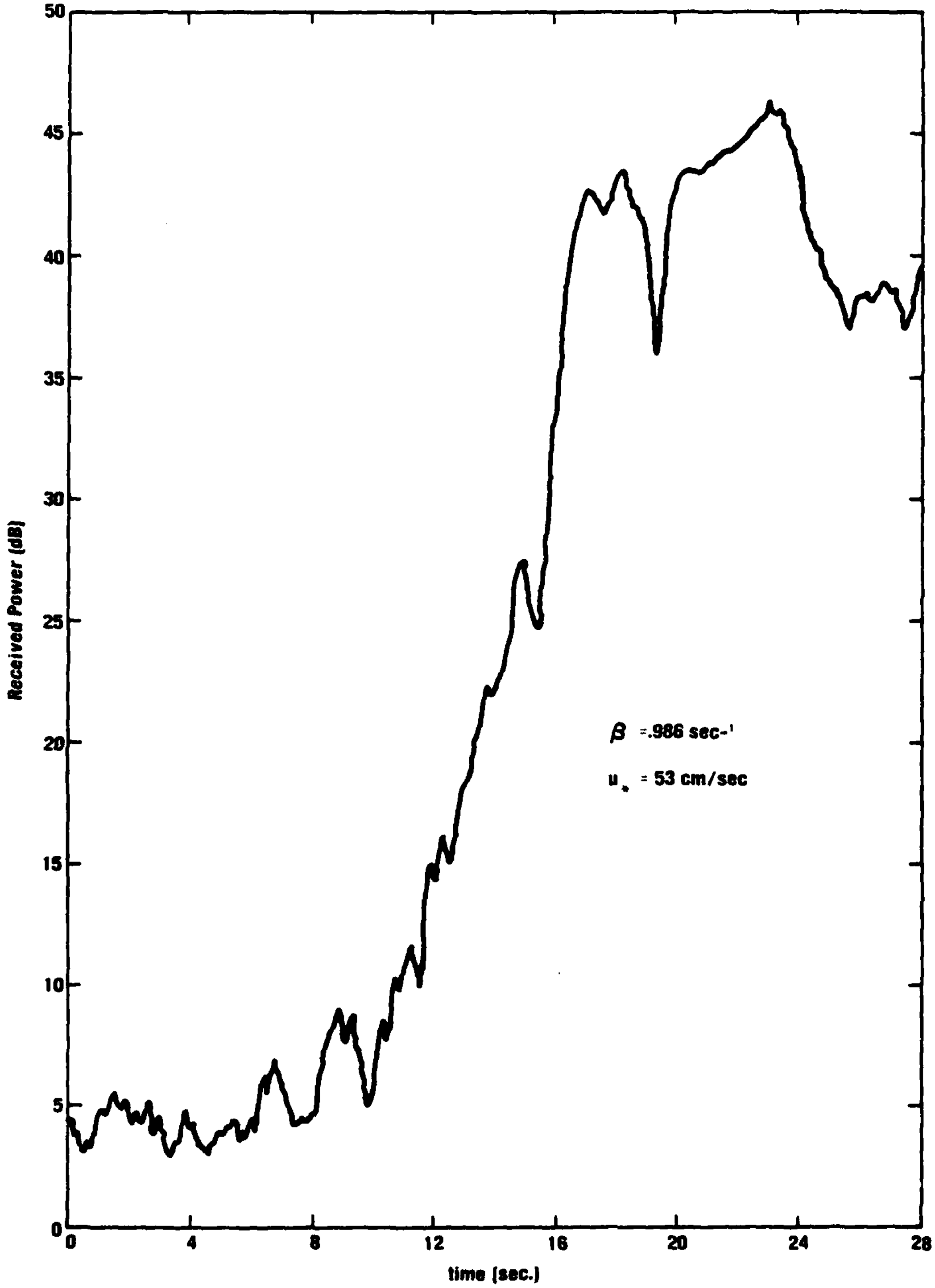

Fig. 12 — Microwave measurements of the growth of a wind-generated water wave with time after the wind is suddenly started. Received power is proportional to the square of the water wave amplitude.

Fig. 13 — An experiment underway at the deep water wave w[illegible] channel to study the effects of wave flow over submerged obstacles. Details of the arrangement and participants are given in reference [illegible]

Fig. 14. — A close-up view of wave flow over half-cylinder in the wave channel. The cylinder was instrumented with an array of pressure ports to measure instantaneous and time-averaged hydrodynamic pressure profiles around the half-cylinder

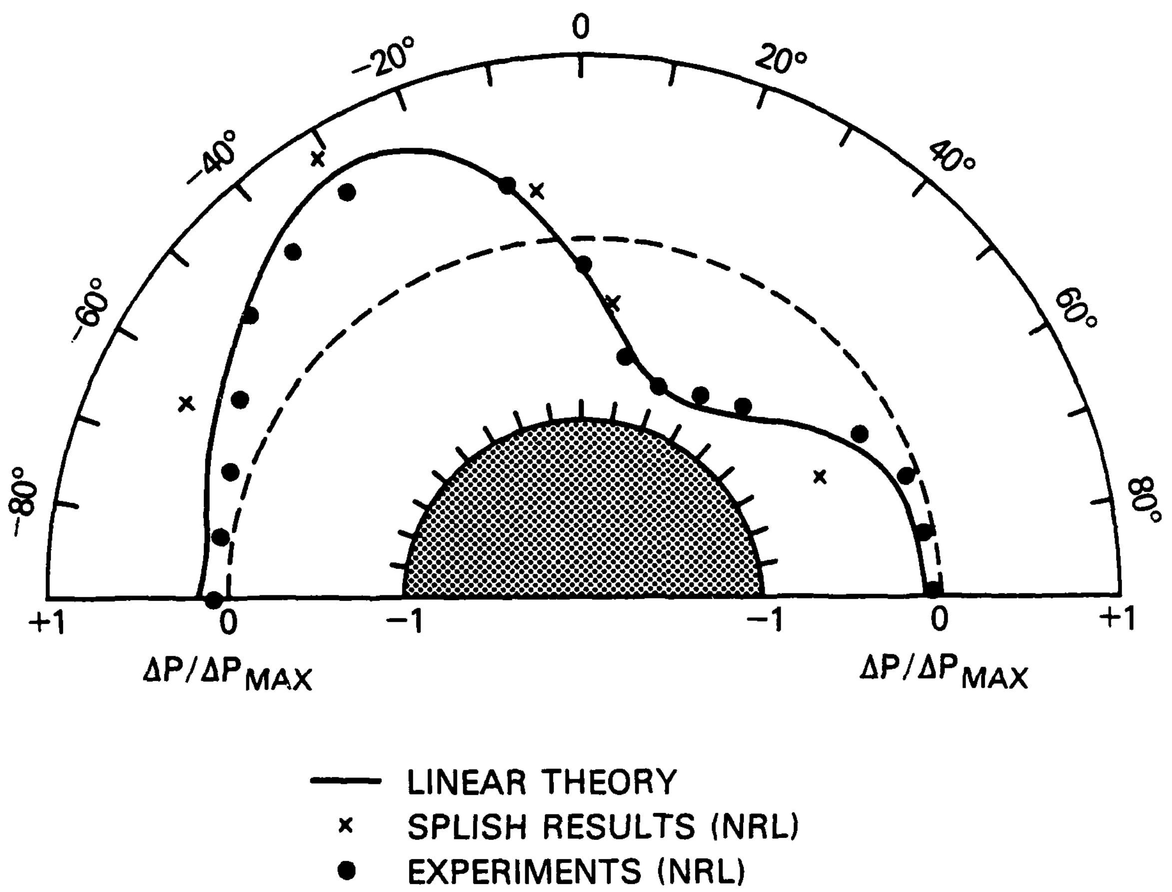

Fig. 15 — A comparison of a measured instantaneous wave-induced pressure profile with numerical calculations of the pressure in the scattering/diffraction wave regime. In this (diffraction) regime the water particle motions are small compared to a typical dimension of the cylinder. The measurements were made using the half-cylinder shown in Fig. 14.

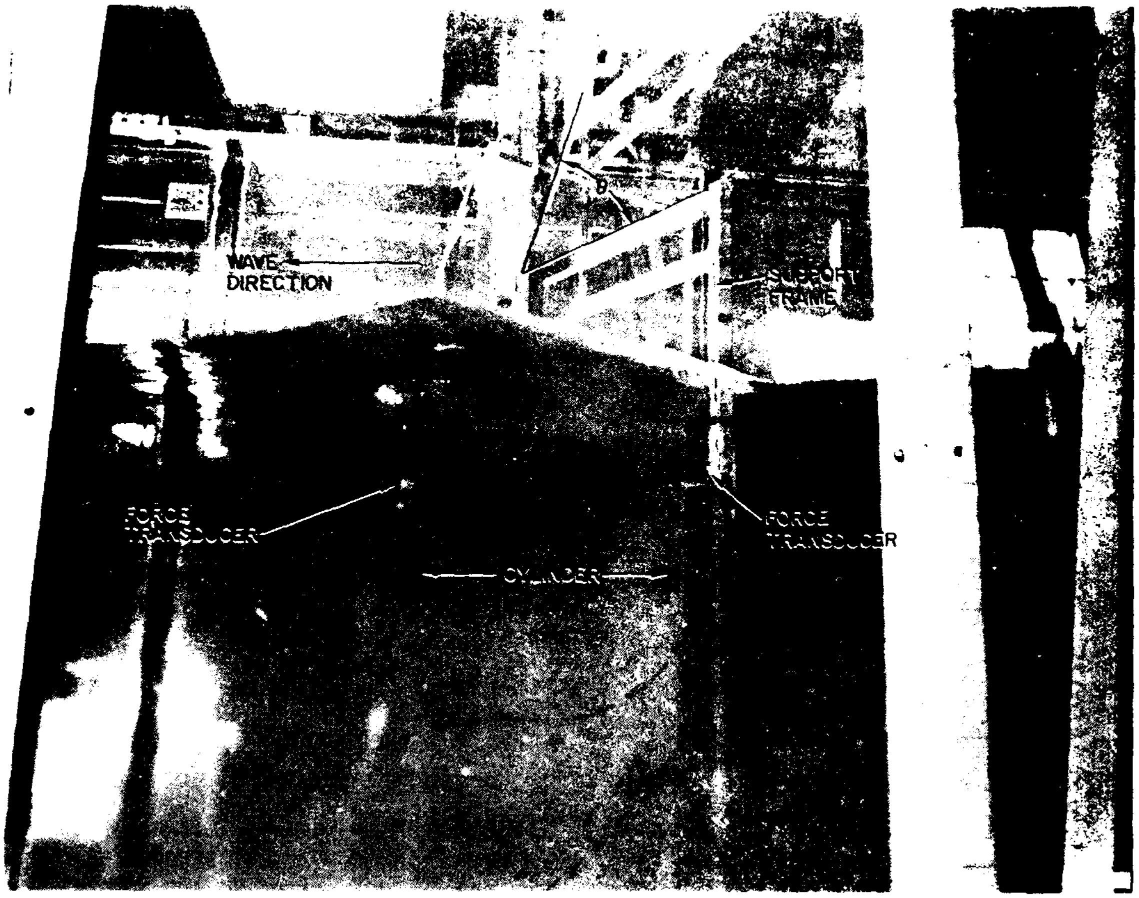

Fig. 16 — A cylinder that was employed in a study of wave forces in the drag-inertia (Morison) regime. The cylinder was fitted with strain gages to measure the wave-induced forces at various water depths, wave lengths and periods

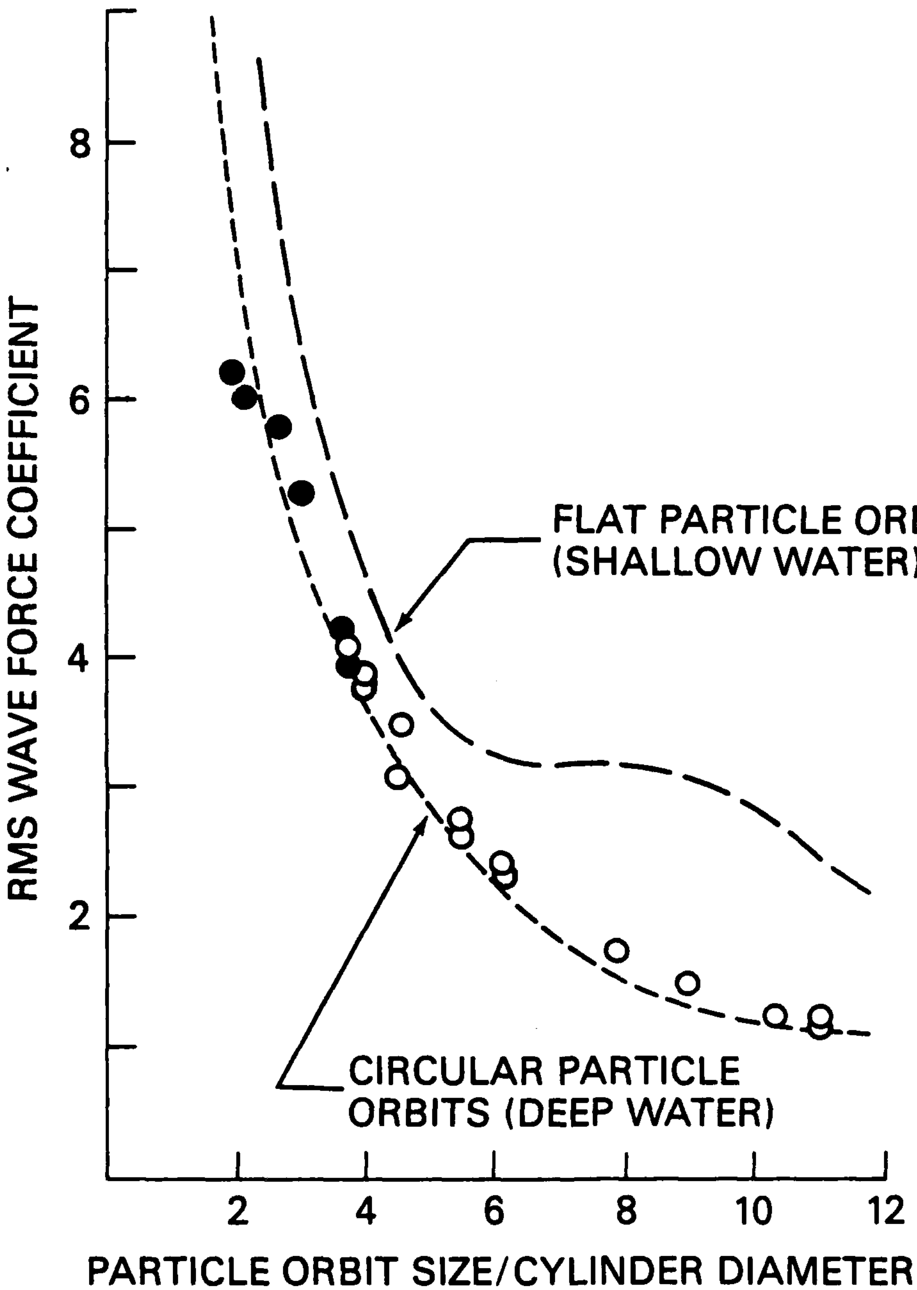

Fig. 17 — Experimental measurements of wave force coefficients in the NRL wave channel. For the case shown in the figure the water particle motions are large compared to a typical dimension (diameter) of the cylinder.

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